Design of Compact Hilbert Microstrip Bandpass Filter For Modern Wireless Communication Systems

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Abstract

This paper presents a new microwave narrow-band bandpass filter with a miniaturized size for use in modern wireless communication systems. The proposed filter design topology is based on a single-mode microstrip resonator constructed in the form of Hilbert fractal geometries from 2nd to 4th iteration levels. The space-filling property the proposed filter topologies possess, has found to produce reduced size structures corresponding to the successive iteration levels. Many filters have been designed for the Industrial Scientific Medical band (ISM band) applications at a design frequency of 2.4 GHz using a substrate with a dielectric constant of 10.8 and thickness of 1.27mm. The performance of each of the resulting bandpass filter structures has been analyzed using a method of moments (MoM) based software package, Microwave Office 2007, from Advanced Wave Research Inc. Results show that these filters possess good transmission and return loss characteristics, besides the miniaturized sizes gained; making them the design specifications of most of wireless communication systems.

Keywords: Single-Mode resonator, narrowband filter, fractal filter, microwave bandpass filter.

تصميم لمرشح امرار نطاقي مصغر من نوع الشريحة الدقيقة لهلبرت لتطبيقات الاتصالات اللاسلكية الحديثة

الخلاصة:

يقدم في هذا البحث تصميم جديد لمرشح إمرار نطاقي ذي حجم مصغر لترددات الموجات الدقيقة . إن المرشح المقترح من نوع الشريحة الدقيقة ذا إمرار نطاقي ضيق لغرض استخدامه في تطبيقات الاتصالات اللاسلكية الحديثة . يتألف تصميم للمرشح المقترح من مرنانات مبنية على أساس ترتيب هلبرت الهندسي من المستوي الثاني إلى الرابع على التوالي . إن خاصية إملاء الفراغ التي تتصف بها تراكيب المرشحات المقترحة تؤدي إلى الحصول على مرشحات ذات أحجام متناقصة بحسب مستويات التكرار المتعاقبة . تم تصميم العديد من المرشحات عند تردد قدره (2.4 كيكاهيرتز) باستخدام شريحة دقيقة ذات ثابت عزل نسبي قدره (10.8) وسمك قدره (1.27 ملليمترا) . تم تحليل أداء كل من المرشحات الناتجة على وفق طريقة إيجاد العزوم(MoM) باستخدام الحقيبة البرمجية(MW2007)من شركة (AWR). بينت نتائج المحاكاة بان هذه المرشحات تمتلك خصائص امرار وانعكاس جيدة بالإضافة إلى الحجم المصغر الناتج مما يجعلها ذات مواصفات تصميمية مناسبة للاستخدام في اغلب أنظمة الاتصالات اللاسلكية الحديثة .

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1. Introduction

Bandpass filter (BPF) is an important component in microwave circuits. Microstrip filters have been widely used in a variety of RF/microwave circuits and systems for their attractive features of low cost, easy fabrication, small sizes and so on. Compact microstrip resonators and filters are important for the next-generation wireless systems, because, with the rapid development of modern communication systems, more and more miniature planar filters with excellent performances are required. [1].

Recent advancements in wireless communication systems have imposed additional motives to design and produce high quality miniaturized components. These motives pioneered microwave circuit and antenna designers to seek out for some treatments by investigating various fractal geometries[1,2] .

Since the pioneer work of Mandelbrot [3], the fractal geometry has found extensive applications in almost all the fields of science. Among these fields are the physical and engineering fields. Several fractal geometries have been applied widely in the fields of antenna and passive microwave circuit design. All of these fractal shape devices have several advantages, including reduced resonant frequencies and broad bandwidth. These characteristics give the fractal shape two unique properties: space filling and self similarity. A fractal shape can be filled on a limited area as the iteration order increases and occupies the same area regardless of the order. This is due to the space filling property. By

self similarity, a portion of the fractal geometry always looks the same as that of the entire structure[4].

Predominantly, fractal research in microwave engineering is concentrated on antennas more than filters because the above properties enable the development of miniaturized, multi-band antennas [4].

Among the earliest predictions of the use of fractals in the design and fabrication of filters is that of Yordanov et.al. Their predictions are based on their investigation of Cantor fractal geometry[5].

Hilbert fractal curve has been used as a defected ground structure in the design of a microstrip lowpass filter operating at the L-band microwave frequency[6]. Sierpinski fractal geometry has been used in the implementation of a complementary split ring resonator [7]. Split ring geometry using square Sierpinski fractal curves has been proposed to reduce resonant frequency of the structure and achieve improved frequency selectivity in the resonator performance.

Koch fractal shape is applied to mm-wave microstrip bandpass filters integrated on a high-resistivity Si substrate. Results showed that the 2nd harmonic of fractal shape filters can be suppressed as the fractal factor increases, while maintaining the physical size of the resulting filter design [4]. Minkowski-like prefractal and Koch curves has been successfully used in producing high performance miniaturized dual-mode microstrip bandpass filters [8,9].

The proposed filter structure is composed of two single-mode Hilbert fractal shaped resonators. Different

filters based on different iterations Hilbert shaped resonator have been designed and their performance has been evaluated for the ISM band applications.

2. The Hilbert Fractal Curve

The Hilbert fractal curve, proposed by Hilbert and introduced by Peano, was known as the space-filling curves. The structure of this shape can be made from a long metallic wire compacted within a microstrip patch. As the iteration order of the curve increases, the Hilbert fractal curve may space-fill the patch. It has been used in various small antenna designs[10].

The Hilbert fractal curve, as outlined in Fig(1), consists of a continuous line which connects the centers of a uniform background grid. The fractal curve is fit in a square section of S as external side. By increasing the iteration level k of the curve, one reduces the elemental grid size as $S/(2^k - 1)$; the space between lines diminishes in the same proportion. For a Hilbert resonator, made of a thin conducting strip in the form of the Hilbert curve with side dimension S and order k, the sum of all the line segments $L(k)$ are given by [11]:

$$L(k) = (2^k + 1)S \qquad ……(1)$$

The main idea here is to increase the iteration of the Hilbert curve as much as possible in order to fit the resonator in the smallest area. However, it has been found that, when dealing with space-filling fractal shaped microstrip resonators, there is a tradeoff between miniaturization (curves with high k) and quality factor of the resonator. For a microstrip

resonator, the width of the strip w and the spacing between the strips g are the parameters which actually define this tradeoff [1,11]. Both dimensions (w and g) are connected with the external side S and iteration level k ($k \geq 2$) by:

$$S = 2^k (w + g) - g \qquad ……(2)$$

From this equation, it is clear that higher levels of fractal iteration imply lower value of microstrip width, thus increasing the dissipative losses with a corresponding degradation of the quality factor[12].

3. Filter Design

The procedure steps of Hilbert fractal bandpass filter design have been represented in the flowchart, as shown in fig(2). At first, a single resonator based on the 2nd iteration Hilbert fractal geometry, has been designed at a frequency of 2.4 GHz. It has been supposed that these filter structures have been etched using a substrate with a relative dielectric constant of 10.8 and a substrate thickness of 1.27 mm. The resulting resonator dimensions have been found to be 6.125× 6.125 mm^2 and a trace width of about 0.42 mm. The performance offered by this resonator is too poor to be presented here. The same resonator with depicted dimensions and substrate specifications has been used to build a two-resonator microstrip bandpass filter. The topology of this filter is shown in Fig 3. The overall dimensions of this filter are of12.43× 6.125 mm^2. The corresponding performance curves are shown in Fig 4.

The previous steps have been repeated, but now with a microstrip

resonator based on the 3rd and 4th iteration Hilbert fractal geometries, designed at the same frequency and using a substrate with the same specifications. Figs 5 and 7 show the topology of the dual-resonator microstrip bandpass filter. These filter have overall dimensions of 9.85× 4.75 mm^2 with a trace width of 0.342 mm and 6.4×3.1 mm^2 with a trace width 0.1 mm, to resonate at the design frequency. Figs 6 and 8 show the related performance curves. The guided wavelength at the design frequency is calculated by (l_g) [13-15]:

$$l_g = c \big/ f \sqrt{e_{eff}} \qquad \text{.....(3)}$$

and

$$e_{eff} = (e_r + 1)/2 \qquad \textbf{.....(4)}$$

Where e_{eff} is effective dielectric coefficient. Table(1) shows results of the modeled Hilbert filter dimensions as designed for 2.4GHz application with corresponding filter performance parameters .Size reduction percentages for 2.4 GHz band of about 39% and 65% have been obtained from 3rd and 4th iteration Hilbert structures as compared with 2nd iteration filter structure. However, both filters possess a considerable miniaturization over the conventional half-wavelength resonator filter. The previous filter designs can be applied for many other wireless communication systems; the filter dimensions can easily be scaled up or down depending on the required operating frequencies. In this case, the resulting filters might be of larger or smaller in sizes according to the

frequency requirements of the specified applications.

4. Filter Performance Evaluation

Filter structures, depicted in Figs 3, 5 , and 7 have been modeled and analyzed at an operating frequency, in the ISM band, of 2.4 GHz using the Microwave Office 2007 electromagnetic simulator from Advanced Wave Research (AWR) Inc. This simulator performs electromagnetic analysis using the method of moments (MoM). The corresponding simulation results of return loss, $S_{11,}$ and transmission, S_{21}, responses of these filters are shown in Figs 4, 6 and 8 respectively. It is clear, that the resulting bandpass filters based on the 2nd to 4th iteration Hilbert fractal geometry offer a quasi-elliptic transmission response with transmission zeros that are symmetrically located around the deign frequency.

The degree of coupling effect depends on width to gap ratio of Hilbert curve strips , which affects resonant frequency of output response[11]. On the other hand, the edge spacing between two resonators and tap position length, can be properly tuned to maximize return loss and minimize insertion loss to optimize frequency response of the filter[16]. Figs(9-11) show the variation of the tap position length on transmission responses from 2nd to 4th iteration Hilbert bandpass filters respectively at design frequency 2.4 GHz. It is worthwhile to observe that the tap position length is not only varying the transmission zeros locations at both sides of passbands , but also affecting sharpness and skirt effect of the resultant response, where

its effect in 3rd and 4th iteration Hilbert designs is stronger than 2nd iteration Hilbert design. Figs(12-14) demonstrate the surface current distribution on the conducting surface of both resonators at the design frequency.

5. Conclusions

A narrowband microstrip bandpass filter design for use in modern wireless communication systems has been introduced in this paper. The proposed filter structures have been composed of dual microstrip resonators based on 2nd , 3rd and 4th iteration Hilbert fractal geometries. The space-filling property the proposed filter structure possesses, results in a high degree of miniaturization with reasonable passband performance, making it suitable for a wide variety of wireless communication applications. The new filter designs have small sizes, compact and low insertion loss as well as high performances, which are very interesting features required for microwave/RF circuit applications. Additional research work has to be carried out to investigate the possibility to design a more compact size dual-mode ring resonator filter based on Hilbert fractal geometry.

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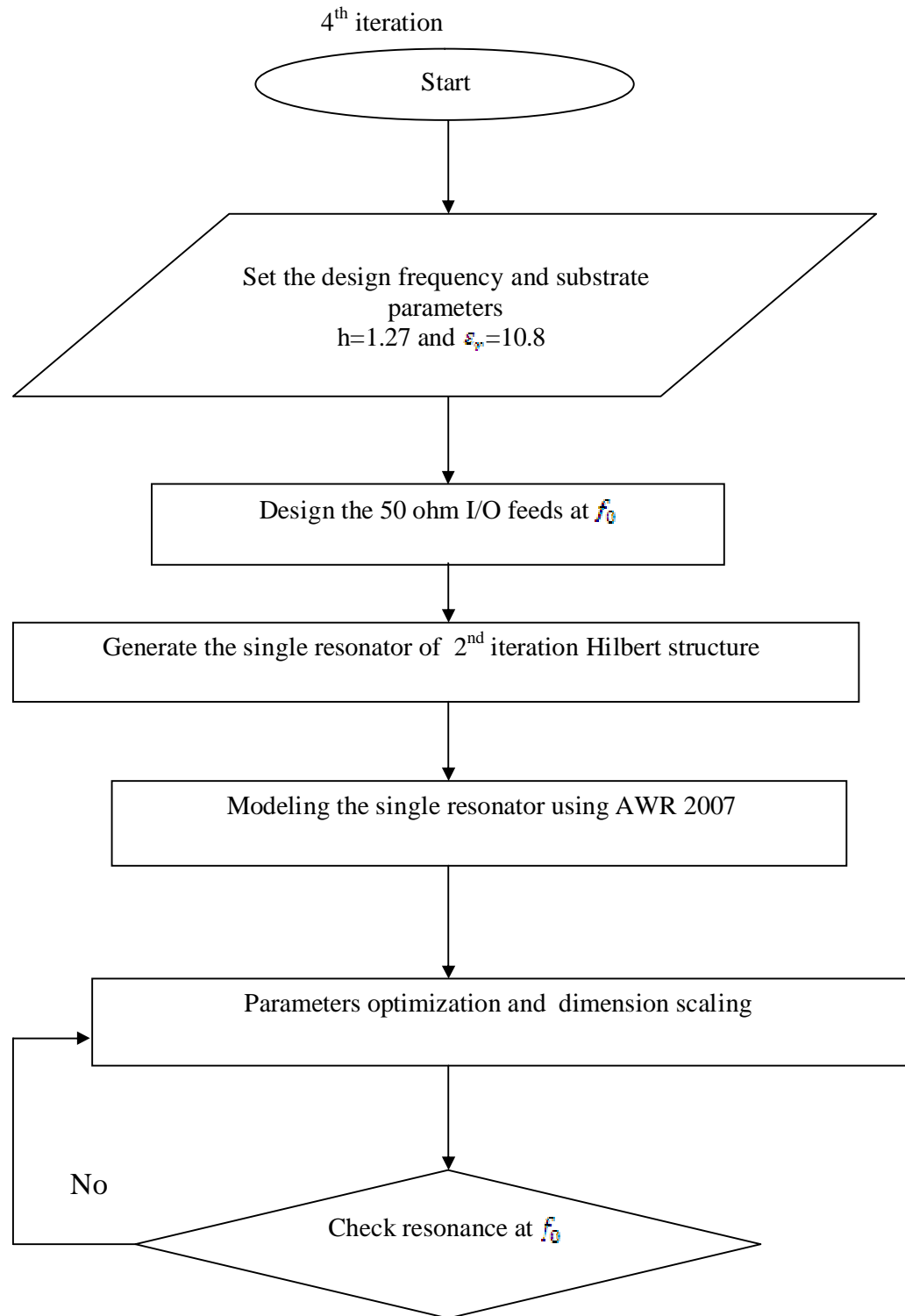[9] J. K. Ali, and N.N. Hussain, A New Fractal Microstrip Bandpass

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**Table (1) Summary of the calculated and simulation
results of the modeled filters**

Filter type Parameter	2nd Iter	3rd Iter.	4th Iter.
Side Length, mm	6.125	4.75	3.1
Occupied Area, mm^2	76.133	46.787	19.4
Size Reduction	-----	39.25%	64.82%
S_{11} (dB)	14.4	13.3	9.46
Insertion Loss(dB)	0.163	0.22	0.525
Fractional Bandwidth (FBW)	11.4% (280 MHz)	6.3% (160 MHz)	10.4% (240 MHz)

(a)   (b)   (c)   (d)
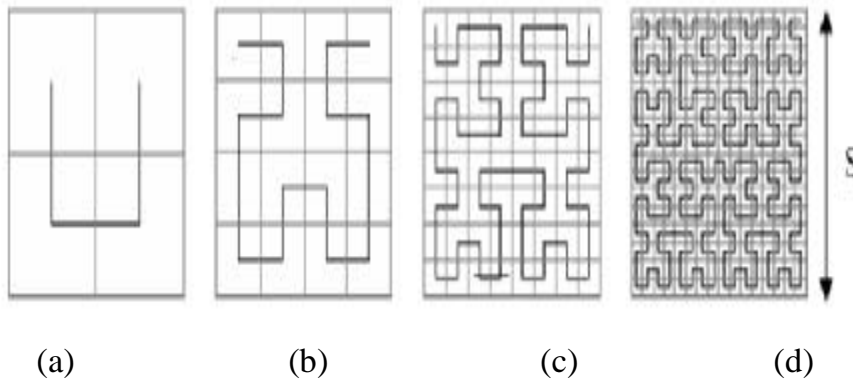
**Figure (1) Hilbert curve iterations (a) 1st iteration (b) 2nd iteration (c) 3rd
iteration (d)**

4th iteration

Start

Set the design frequency and substrate parameters
h=1.27 and ε_r=10.8

Design the 50 ohm I/O feeds at f_0

Generate the single resonator of 2nd iteration Hilbert structure

Modeling the single resonator using AWR 2007

Parameters optimization and dimension scaling

Check resonance at f_0

No
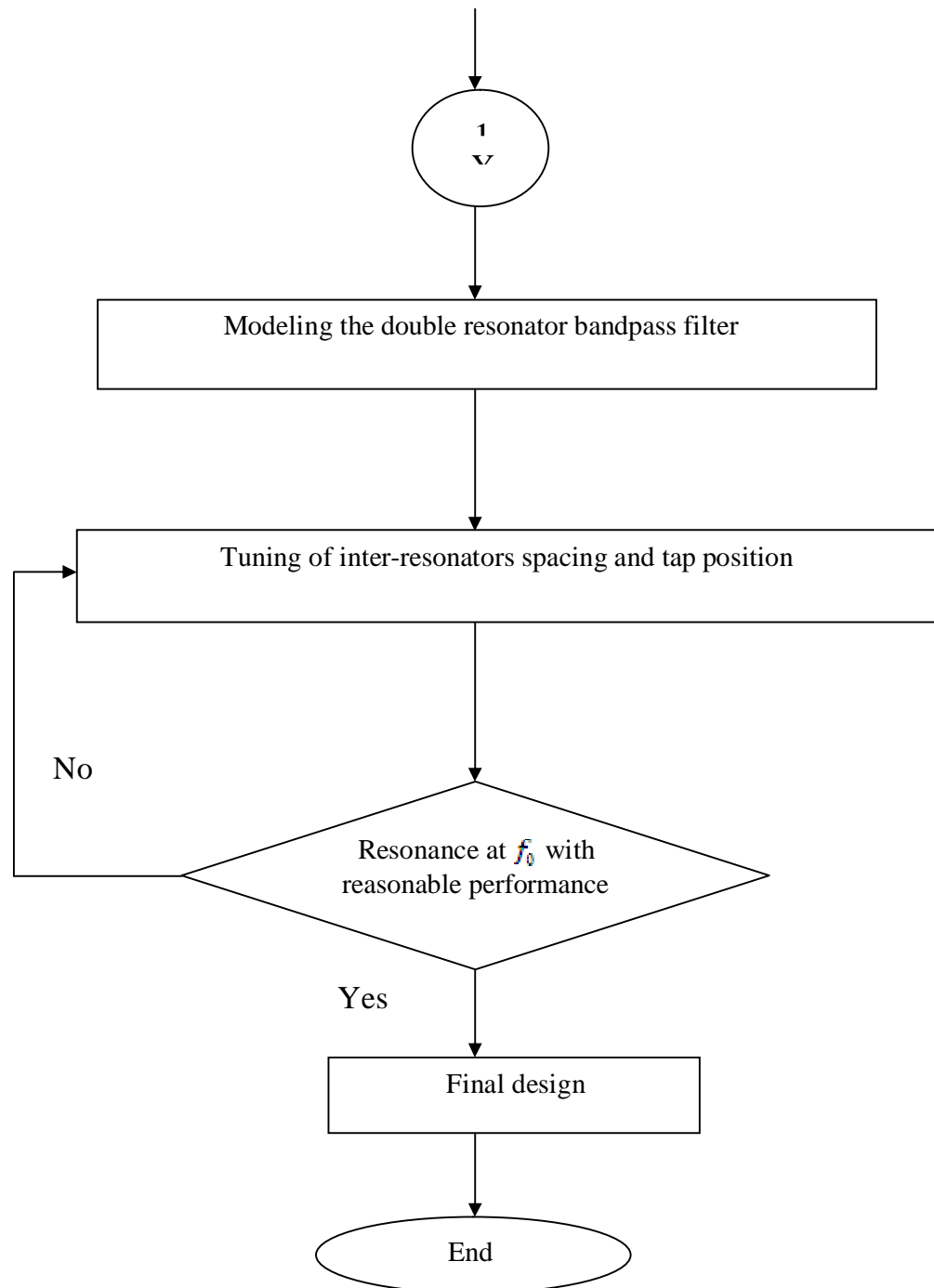
Figure (2) Flowchart for the designing of Hilbert fractal BPF
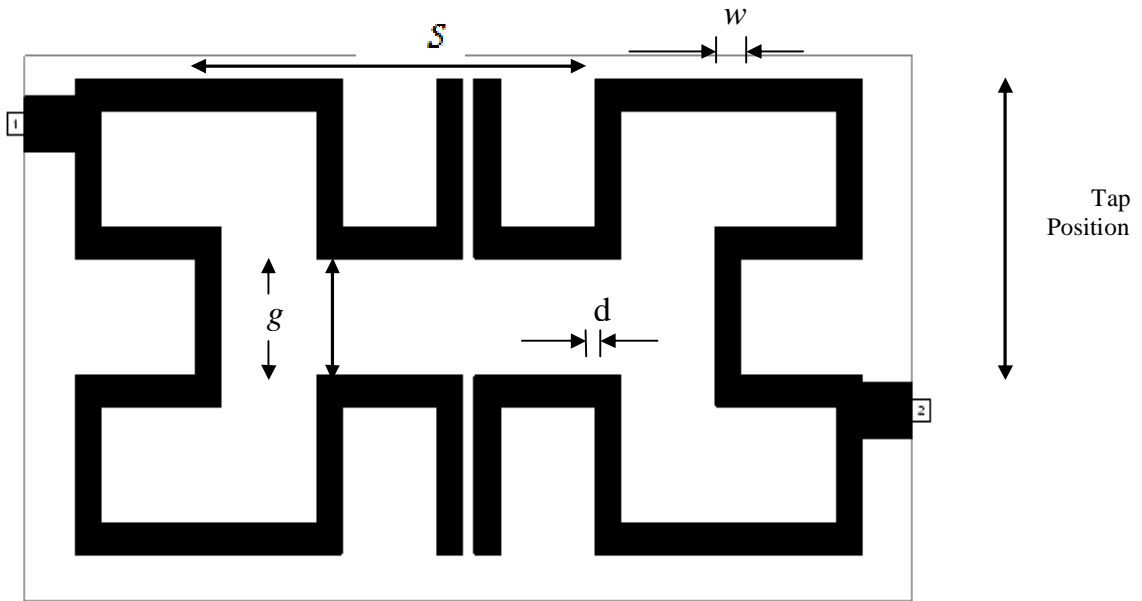
Figure (3) The modeled layout of 2ⁿᵈ iteration two unstubbed Hilbert resonators BPF
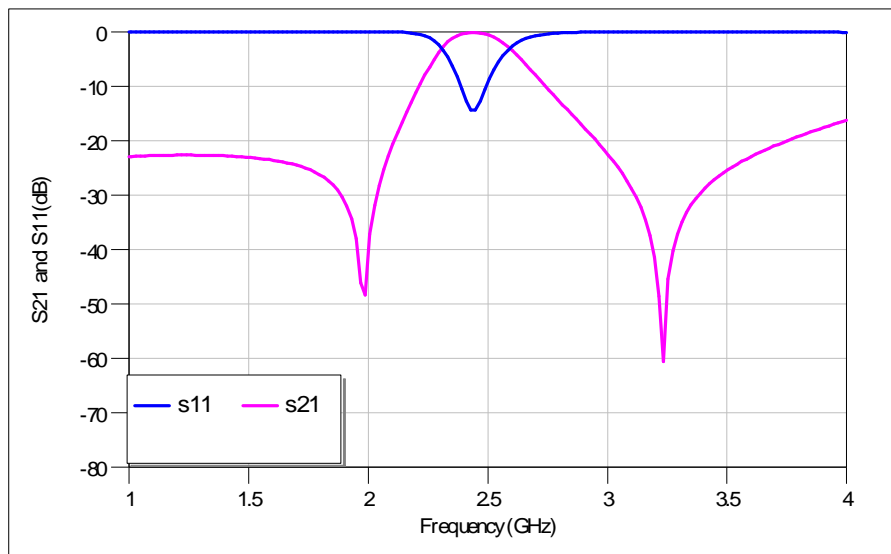
Figure (4) The return loss and transmission responses of the 2ⁿᵈ iteration two unstubbed Hilbert resonators BPF designed for 2.4 GHz
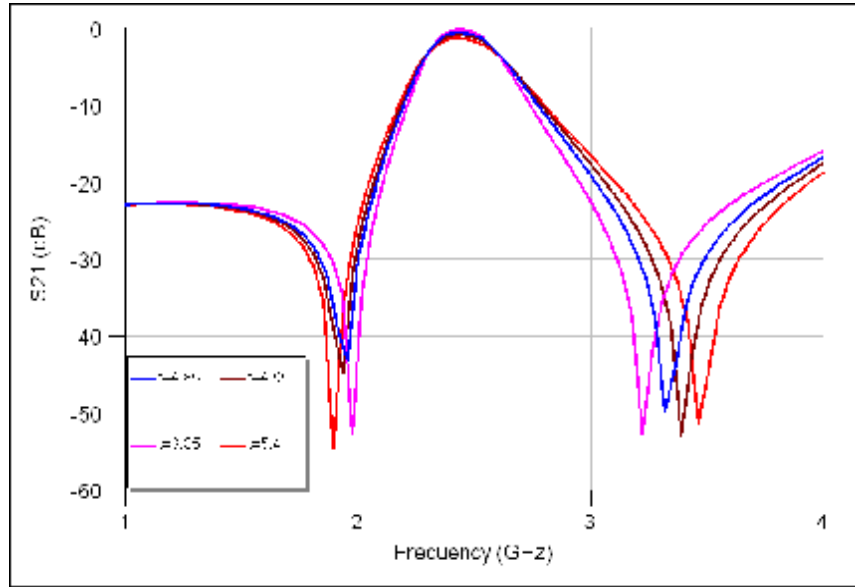
S

g

Tap
Position

w

d
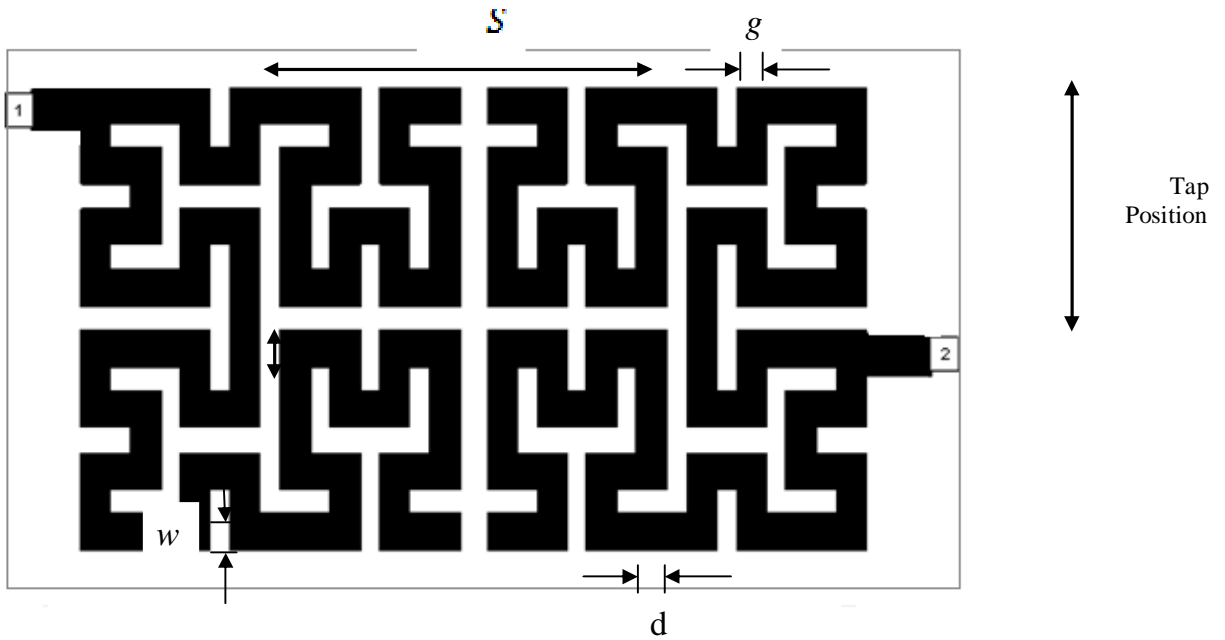
Figure(5) The modeled layout of 3rd iteration two unstubbed Hilbert resonators BPF
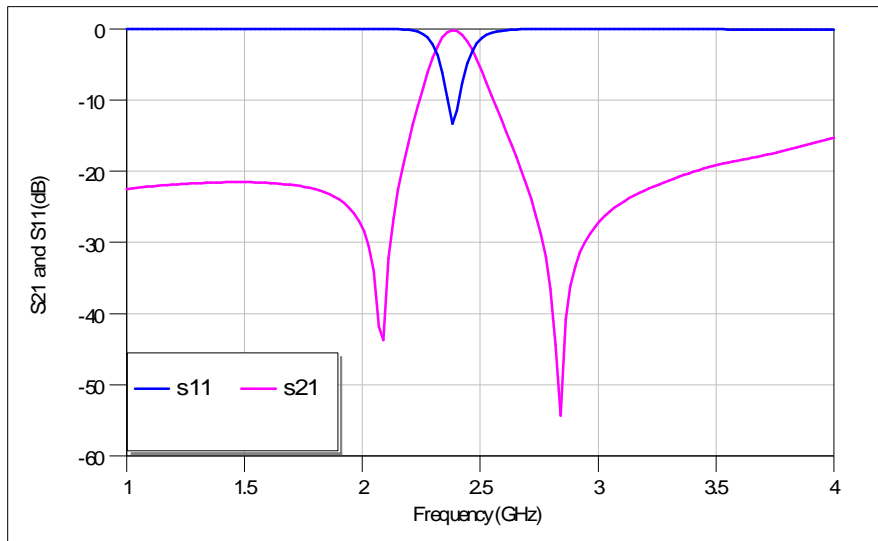
Figure (6) The return loss and transmission responses of the 3rd iteration two unstubbed Hilbert resonators BPF designed for 2.4 GHz

$\mathcal{S}$

g

Tap
Position

w

d
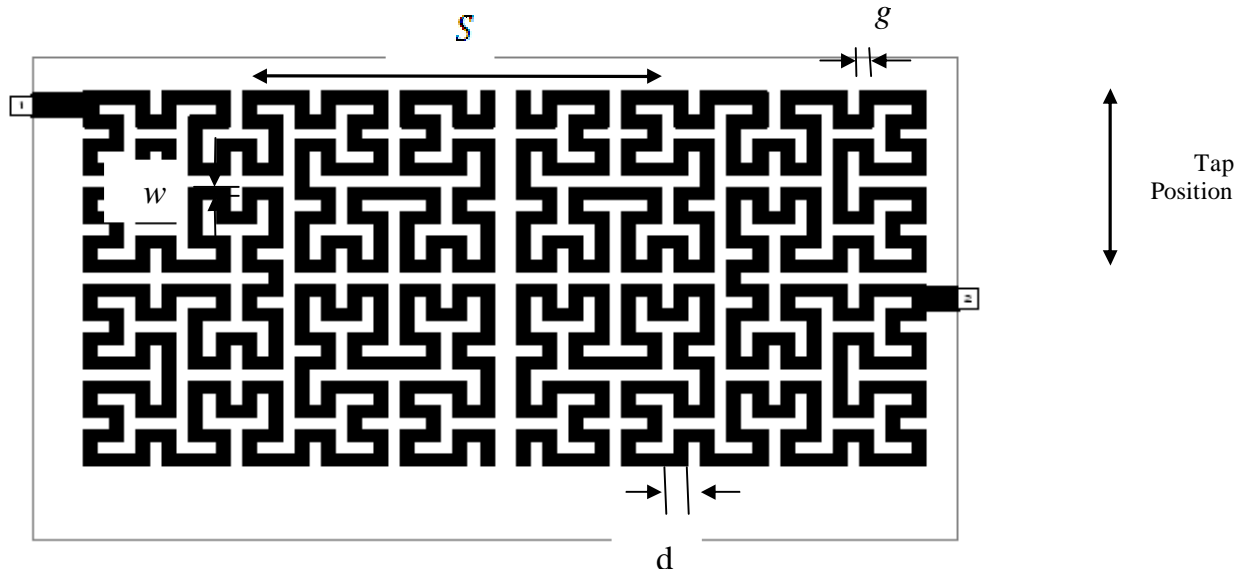
**Figure (7) The modeled layout of 4th iteration two unstubbed Hilbert
resonators BPF**
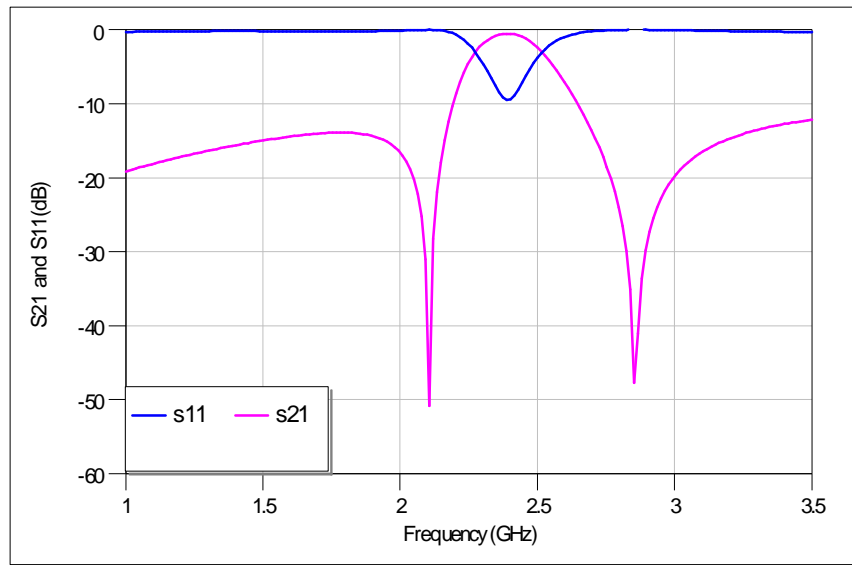
**Figure(8) The return loss and transmission responses of the 4th iteration two
unstubbed Hilbert resonators BPF designed for 2.4 GHz**

Figure (9). The transmission responses of the resulting 2nd iteration two unstubbed Hilbert resonators BPF of different tap position lengths, t, (in mm)
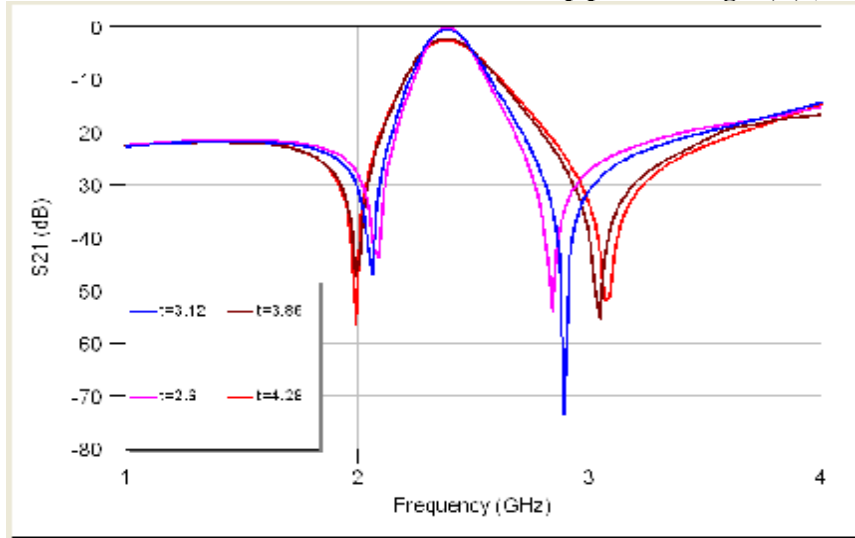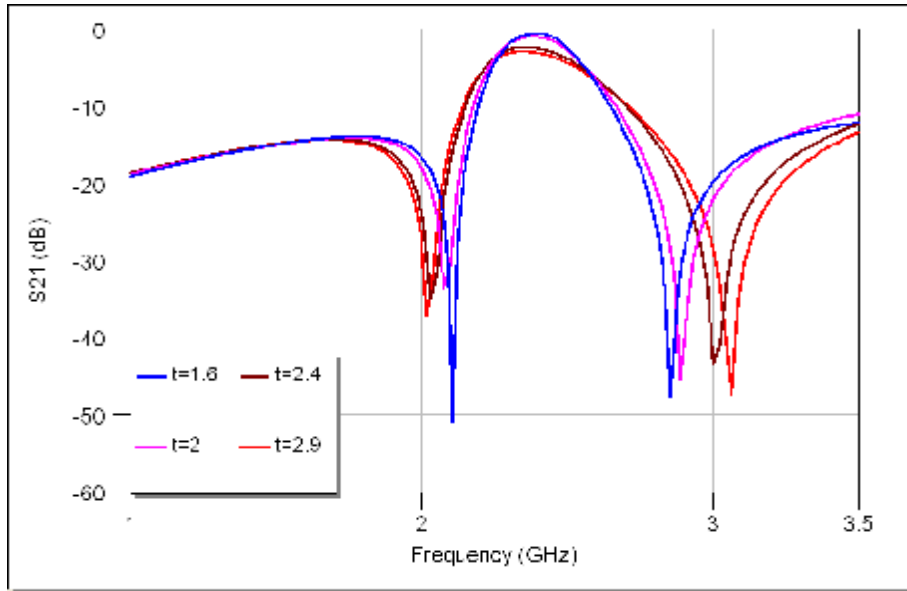

Figure (10) The transmission responses of the resulting 3rd iteration two unstubbed Hilbert resonators BPF of different tap position lengths, t, (in mm).

**Figure(11) The transmission responses of the resulting 4th iteration two
unstubbed Hilbert resonators BPF of different tap position lengths, t, (in mm)**
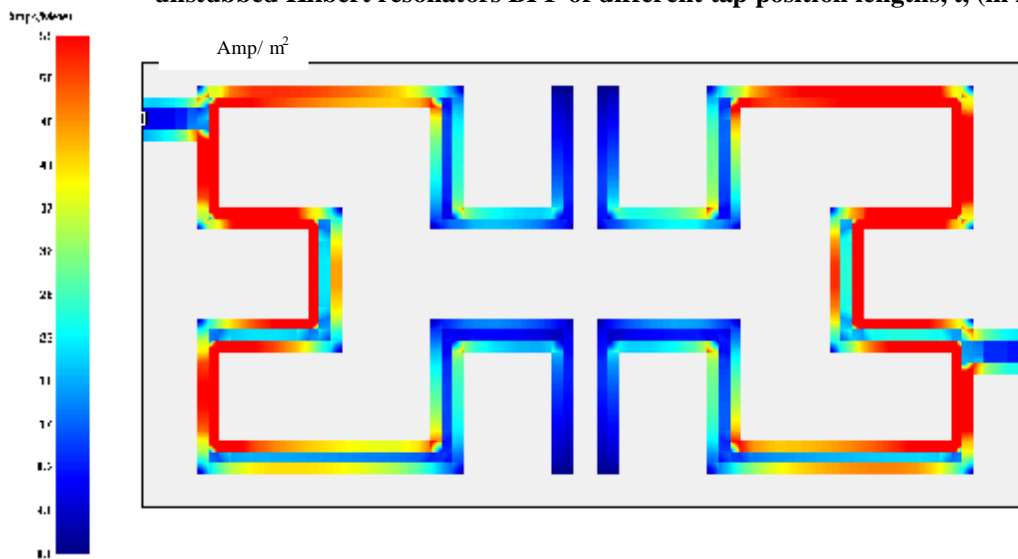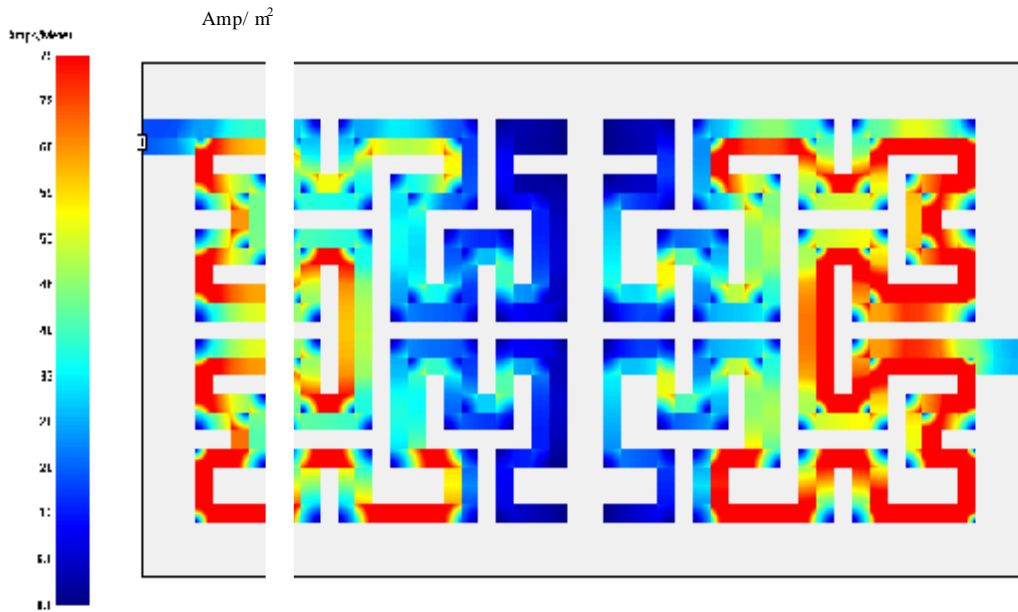

**Figure (12) Current density distribution at the conducting surface of the 2nd
iteration unstubbed Hilbert bandpass filter simulated at a resonant frequency
of 2.4GHz**

Amp/ m^2

Figure(13) Current density distribution at the conducting surface of the 3rd iteration unstubbed Hilbert bandpass filter simulated at a resonant frequency of 2.4 GHz
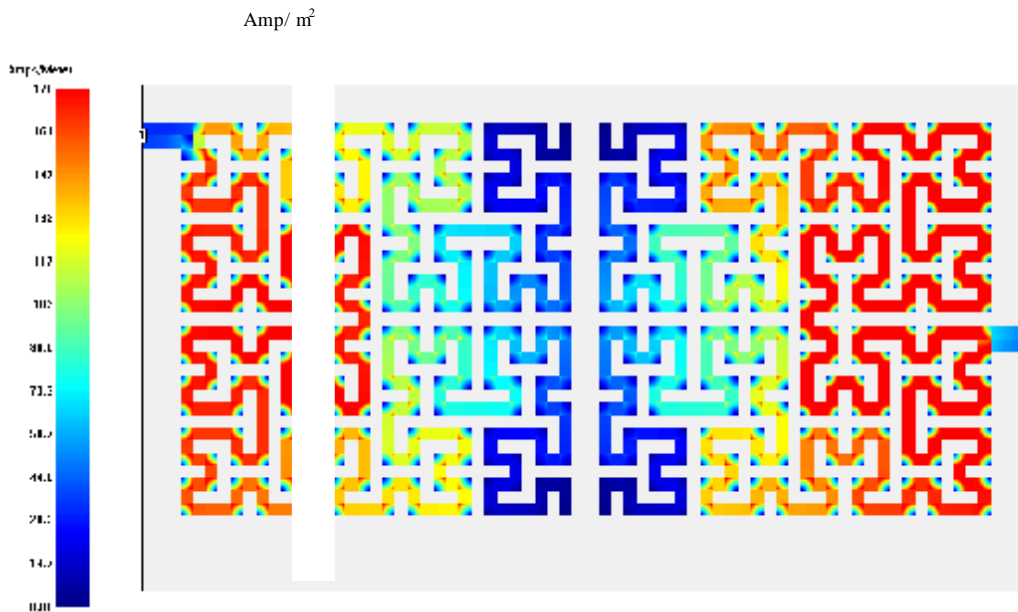
Amp/ m^2

Figure (14) Current density distribution at the conducting surface of the 4th iteration unstubbed Hilbert bandpass filter simulated at a resonant frequency of 2.4GH